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THE INFLUENCE OF ENGINEERING ETHICS ON ECOLOGY AND SUSTAINABLE DEVELOPMENT

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Abstract: Engineering is an important and learned profession, which has a direct and vital impact on the quality of life for all people. Engineers have to be aware of the fact that by using available engineering technologies it is possible to provide abundance for all human beings, but also to destroy all life on Earth. Accordingly, engineers should be committed to improving the environment to enhance the quality of life and to sustain the balance in nature. They shall hold the safety, health and welfare of the public as paramount, and strive to comply with the principles of sustainable development.
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INTRODUCTION

The end of the twentieth and the beginning of the twenty-first century are marked by developments in science which is considered to be the basis of the greatest quantitative and qualitative changes in history. We are witnesses to great benefits to mankind stemming from contemporary engineering development. The nuclear and space age that we live in, encourage the vigorous progress of science. Human technologies are developing very fast. Mechanization, automation and computerization of production processes have lessened the hazards to human physical integrity, but in spite of that, man's psychic and moral integrity in his working environment has been increasingly endangered. Modern technology has a deep impact on humankind and all life on Earth. Unfortunately, we frequently are witnesses of more and worse or even tragic consequences of scientific and technological advances markedly caused by neglecting moral principles in people's activities. The decisions and actions of engineers seriously affect the world we live in, and society at large. Engineers have to be aware of their responsibility, dignity and ethics as they make choices during their professional practice and they should not think only about profit. Therefore, a clear understanding of engineering responsibility, dignity and ethics is needed like never before.

Engineering ethics, as the field of applied ethics, is the application of philosophical and moral systems to the proper judgment and behavior by engineers in conducting their work, including the products and systems they design and the consulting services they provide. Thus, engineering ethics is defined as the rules and standards governing the conduct of engineers in their roles as professionals, and is concerned with determining the standards in engineering ethics and applying them to particular situations.

Viewing ethics as core values of human life leaves us with many important questions. Real ethics or the values behind them cannot and should not change with time, although their expression or focus may change. But nowadays we can see that human morality has declined drastically and that the ethical standards in society are very low. Engineering really improves and enriches human life but also endangers it. We have to be aware of the fact that by using available engineering technologies it is possible to provide abundance for all human beings, but also to destroy all life on Earth. Therefore modern engineers have to study and apply ethical codes, doctrines and principles in their professional engineering practice.

In the modern era, engineering profession is no longer a pure technical discipline. Therefore it is no longer possible to practice engineering without regard for the ethical context. Many engineers will face unethical situations beyond their control during their careers. However, the situation in which the engineer will take action based on the ethical dilemma, is a matter of personal choice e.g. a change of workplace or attempting to change things from the inside [1].

CONSEQUENCES OF NUCLEAR POWER PLANT DISASTERS

Nuclear power is one of the most powerful technologies humans have developed. Whether in power plants or more obviously in weapons, nuclear fission and fusion release tremendous energies and lethal byproducts. This is human power at its mightiest, and therefore ethics must here be at its mightiest as well. But it is not, hence disaster. The moral imperative with immense power is to care for it with great responsibility, to control it and direct it towards the good. It is obvious that with great power comes great responsibility.

Unlike fossil fueled power plants which stop generating heat when the fuel supply is cut, nuclear reactors generate heat until the main fission reaction has been shut down and all fission byproducts have decayed to a reasonable level. Therefore, a cooling system failure leads to a reactor core meltdown. Technology could prevent this nuclear calamity if only it is properly applied to the problem. Science could gauge the risk, and technology could mitigate it more effectively. We need to step up and take responsibility. We have more power than we admit. And in choosing not to act, we are choosing to accept the risk of disaster.

Examples of possible ethical dilemmas, regarding nuclear power plant disasters, that may occur, are discussed on the following cases.

Case 1: Chernobyl Nuclear Power Plant Disaster

The large environmental disaster, on 26 April 1986, caused by the meltdown at the nuclear power plant near Chernobyl, Ukraine, dramatically changed the world's opinion about using nuclear reaction for power [2, 3]. The Chernobyl nuclear power plant was built in the wooded marshlands of northern Ukraine, approximately 80 miles north of Kiev. Its first reactor went online in 1977, the second in 1978, third in 1981, and fourth in 1983; two more were planned for construction. A small town, Pripyat, was also built near the Chernobyl nuclear power plant to house the workers and their families.

The unit 4 reactor was to be shut down for routine maintenance on 25 April 1986. It was decided to take advantage of this shutdown to determine whether, in the event of a loss of station power, the slowing turbine could provide enough electrical power to operate the main core cooling water circulating pumps, until the diesel emergency power supply became operative. The aim of this test was to determine whether cooling of the core could continue to be ensured in the event of a loss of power. Adequate coolant circulation following completion of the test was secured by arranging power supplies to four of the eight pumps from station service power; the other four pumps were supplied by unit service power. This type of test had been run the previous year, but the power delivered from the running down turbine fell off too rapidly, so it was decided to repeat the test using the new voltage regulators that had been developed. Unfortunately, this test, which was considered essentially to concern the non-nuclear part of the power plant, was carried out without a proper exchange of information and coordination between the team in charge of the test and the personnel in charge of the safety of the nuclear reactor. Therefore, inadequate safety precautions were included in the test program and the operating personnel were not alerted to the nuclear safety implications of the electrical test and its potential danger. Two electrical engineers, not nuclear but electrical engineers were in charge of the control room.

The shutdown and test began at 1 a.m. on April 25th. To get accurate results from the test, the operators turned off several of the safety systems, which turned out to be a disastrous decision. In the middle of the test, the shutdown had to be delayed nine hours because of a high demand for power in Kiev. The shutdown and test continued again at 11:10 p.m. on the night of April 25th. Just after 1 a.m. on April 26th, the reactor's power dropped suddenly, causing a potentially dangerous situation. The operators tried to compensate for the low power but the reactor went out of control. If the safety systems had remained on, they would have fixed the problem; however, they were not. It was discovered that valves were padlocked in the open position so that they would not automatically shut down and turn off this experiment. The reactor exploded at 1:23 a.m. Two explosions were reported, the first being the initial steam explosion, followed two or three seconds later by a second explosion, possibly from the build-up of hydrogen due to zirconium-steam reactions. Fuel, moderator, and structural materials were ejected, starting a number of fires, and the destroyed core was exposed to the atmosphere (Figure 1). One worker, whose body was never recovered, was killed in the explosions, and a second worker died in hospital a few hours later as a result of injuries received in the explosions.

The world discovered the accident two days later, on April 28th, when operators of the Swedish Forsmark nuclear power plant in Stockholm registered unusually high radiation levels near their plant. When other plants around Europe began to register similar high radiation readings, they contacted the Soviet Union to find out what had happened. The Soviets denied any knowledge about a nuclear disaster until 9 p.m. on April 28th, when they announced to the world that one of the reactors had been damaged.

While trying to keep the nuclear disaster a secret, the Soviets were also trying to clean it up. At first they poured water on the many fires, and then they tried to put them out with sand and lead and then nitrogen. It took nearly two weeks to put the fires out. Citizens in the nearby towns were told to stay indoors. Pripyat was evacuated on April 27th, the day after the disaster had begun; the town of Chernobyl wasn't evacuated until May 2, six days after the explosion.

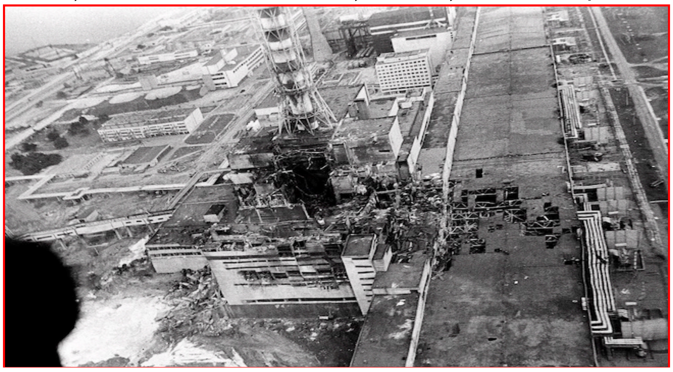

Figure 1 *– The nuclear reactor after the disaster [4]*

Physical clean-up of the area continued. Contaminated topsoil was placed into sealed barrels and radiated water contained. Soviet engineers also encased the remains of the fourth reactor in a large, concrete sarcophagus to prevent additional radiation leakage. The sarcophagus constructed quickly and in dangerous conditions, had already begun to crumble by 1997. An international consortium has begun plans to create a containment unit that will be placed over the current sarcophagus. It is expected to be completed in 2013. It is estimated that the radiation from the Chernobyl disaster was 100 times more powerful than the bombs dropped on Hiroshima and Nagasaki. Thirty-one people died shortly after the explosion, but thousands more will die from the long-term effects of radiation.

The accident caused the largest uncontrolled radioactive release into the environment ever recorded for any civilian operation, and large quantities of radioactive substances were released into the air for about 10 days. This caused serious social and economic disruption for large populations in Belarus, Russia and Ukraine. Technological disasters, unfortunately, cannot be broken down into one single root cause. The Chernobyl disaster is no exception to this principal.

Chernobyl shows the frequent disjuncture between science and technology. This can be shown by looking at the control rod design flaw. This flaw had to do with the speed in which control rods could be inserted. In reactors throughout the rest of the world, this process takes about two seconds. However, at Chernobyl, full insertion took about twenty seconds which was much too slow and contributed to the runaway of the core. The Chernobyl reactor had two crucial design flaws. First, it used graphite (carbon) instead of water to "moderate" the neutrons, which makes possible the nuclear reaction. The graphite caught fire in April 1986 and burned for four days. Water does not catch fire. Second, Chernobyl had no containment structure. When the graphite caught fire, it spouted a plume of radioactive smoke that spread across the globe. A containment structure would have both smothered the fire and contained the radioactivity.

The RBMK reactor was the type involved in the Chernobyl disaster. RBMK is an abbreviation for the Russian reaktor bolshoy moshchnosti kanalniy which means High Power Channel-type Reactor, and describes a class of graphite-moderated nuclear power reactor which was built in the Soviet Union for use in nuclear power plants to produce nuclear power from nuclear fuel. RBMK reactors don't have an exhaust gas system or a containment structure. A containment structure, similar to those built on reactors all over the world, would not only have slowed the release of radioactive material but significantly reduced the amount released, as this type of containment system is highly effective.

During the entire time the Chernobyl was active, no emergency plans were ever created. Because of this, local authorities were completely unprepared for the disaster. There weren't any medical supplies, protective clothing, or even devices to measure radioactivity on hand. This unpreparedness also contributed to an inefficient evacuation. For example, the city of Pripyat, which lies less than five kilometers away from ground zero, wasn't even informed of the explosion until thirty-six hours afterwards. It also took seven days to ban the consumption of local agricultural products. These mishandlings led to even higher mortality and morbidity rates [5].

As a result of the Chernobyl accident, tens of thousands of hectares of forests have experienced massive radioactive contamination. These were mainly single-crop plantings of Scotch pine (Pinus silvestris). It wasn't just people, animals and trees that were affected by radiation exposure at Chernobyl, but also the decomposers: insects, microbes and fungi. As a consequence, trees in the infamous Red Forest (Figure 2), an area where all of the pine trees turned a reddish color and then died shortly after the accident, did not seem to be decaying, even 15 to 20 years after the meltdown. Normally, in the areas with no radiation, 70 to 90 percent of the leaves were gone after a year. But in places where more radiation was present, the leaves retained around 60 percent of their original weight. Obviously radiation inhibited microbial decomposition of the leaf litter on the top layer of the soil and nutrients aren't being efficiently returned to the soil [6, 7, 8].

The Red Forest refers to the trees in the 10 km^2 surrounding the Chernobyl Nuclear Power Plant within the Exclusion Zone. The name Red Forest comes from the ginger-brown color of the pine trees after they died following the absorption of high levels of radiation from the Chernobyl accident (Figure 2). The site of the Red Forest remains one of the most contaminated areas in the world today [6, 7, 8].

Unfortunately, Chernobyl is a costly lesson in technological disasters. Many say the root cause of the accident is found in the human elements and although this may be the largest contributor, one also has to look at the technical design, organization and socio-cultural factors. But it is clearly evident that what blew up Chernobyl was not a lack of knowledge. It was a lack of ethics. That's a very important lesson for the 21st century.

***Figure 2** – Red Forest - dead forests in the 10 km^2 surrounding the Chernobyl Nuclear Power Plant [6].*

Case 2: Fukushima Daiichi Nuclear Power Plant Disaster

On Friday, March 11, 2011, one of the largest earthquakes, measuring 9.0 on the Richter scale, in the recorded history of the world, occurred on the east coast of northern Japan. This earthquake also generated a major tsunami, causing nearly 20,000 deaths [9]. Electricity, gas and water supplies, telecommunications, and railway service were all severely disrupted and in many cases completely shut down. Eleven nuclear reactors at four nuclear power plants in the region were operating at the time and all shut down automatically when the quake hit. Subsequent inspection showed no significant damage to any from the earthquake [10].

Not far from the epicenter of this quake, within the Fukushima Prefecture, was the Fukushima Daiichi nuclear power complex, including three functioning and three off-line boiling water reactors. After the earthquake, the power of the plant was lost. Emergency diesel generators provide power for the emergency core cooling systems for a short time. Following a major earthquake, a 14 meters tsunami overtops the seawall, designed to protect the plant from a *tsunami of 5,7 meters, disabled the diesel generators power supply and cooling of three Fukushima Daiichi reactors, causing a nuclear accident on 11 March 2011 [9, 10]. All three cores largely melted in the first three days. These disruptions severely affected the Fukushima Daiichi nuclear power plant, causing a release of radioactive materials from the reactors (Figure 3). A large amount of radioactive water has leaked from a holding tank at Fukushima Daiichi nuclear power plant in to the ocean. Tokyo Electric Power Company (TEPCO) admitted that up to 20 trillion becquerels of cesium-137, 10 trillion becquerels of strontium-90 and 40 trillion becquerels of tritium entered the ocean via groundwater, between May 2011 and August 2013. European Union study has determined that just 3 months following the 2011 Fukushima Daiichi disaster, the land area larger than 20,000 square miles around Fukushima was contaminated with radioactive nuclides. Cesium and radioactive iodine were among them. In Canada, USA and Mexico contaminated ocean water from Fukushima Daiichi was also found, as well as contaminated seafood and tuna fish [11, 12]. More than 43 million people in Japan were likely exposed to these cancer-causing elements [13]. These radioactive substances still pour into the Pacific to this day, as determined by a team of scientists [11, 12].*

This is an overview of the nuclear disaster. Who are to blame for it? Recently, some critics began to focus on the negligence of the management side in TEPCO [14, 15]. They say a decisive factor of this disaster consists in the misjudgment of the managers. What about engineers at the site? Did they take proper action? With regard to the action taken by the engineers as subordinates in TEPCO, they did their best in contrast with their managers [14]. What about the designers of the reactors? It is American company, General Electric (GE) that is often mentioned in this context. Indeed, the designs depended on ideas of GE's. Some Japanese engineers recently confessed that they did not have enough knowledge to criticize GE's idea at that time [14]. The problem is that all cooling systems in Fukushima Daiichi nuclear power plant required electrical power. Thus, in the case of a station black out, they all stop working. And this exactly happened, as emergency diesel generators were disabled by the tsunami and caused a station blackout. The subsequent lack of cooling led to explosions and meltdowns at the Fukushima facility, with problems at three of the six reactors.

What about the responsibility of seismologists? In face of the earthquake, not a few seismologists in Japan mentioned their defeat, pointing out that seismologists admitted the limitation of their science: unpredictability of an earthquake [14]. Every year, a large amount of money is spent in Japan in huge facilities to predict earthquakes, but earthquakes cannot be reliably predicted. Of course, unpredictability of earthquakes does not imply uselessness of seismology. Unfortunately, it is obvious that the construction of nuclear power plants is essentially not concerned with the researches of seismology.

The Fukushima Daiichi nuclear plant is located in Japan, which, like the rest of the Pacific Rim, is in an active seismic zone. The International Atomic Energy Agency (IAEA) had expressed concern about the ability of Japan's nuclear plants to withstand seismic activity. At a 2008 meeting of the G8's Nuclear Safety and Security Group in Tokyo, an IAEA expert warned that a strong earthquake with a magnitude above 7.0 could pose a serious problem for Japan's nuclear power stations [16].

Perhaps the Fukushima Daiichi nuclear plant was not adequately located or engineered? It probably should not have been built at all, or if it had to be located where it is, it should have been more strongly constructed and had better backup systems.

The nuclear crisis in the Japanese power plant at Fukushima also raises profound environmental ethical questions about risk and how we handle it. Fukushima Daiichi was fatally crippled during the historic devastation caused by the earthquake and tsunami on 11 March 2011 that ravaged Japan's northeastern coast. Radiation releases caused large evacuations, concern over food and water supplies, and treatment of nuclear workers. Radioactive contamination was discovered in air, soil, water, sea, vegetable and milk samples. For years, TEPCO, the operator of the Fukushima power plant, has been widely criticized for deadly accidents and improper inspections [15, 16]. The Fukushima disaster is another ethical example of the tragic nadir in a history of poor management at the company's nuclear facilities.

Figure 3 *– Fukushima Daiichi nuclear disaster - four damaged reactor buildings [9].*

The lives of hundreds of thousands of people continue to be affected by the Fukushima nuclear disaster, especially the 160,000 who fled their homes because of radioactive contamination, and continue to live in limbo without fair, just, and timely compensation. They have only a false hope of returning home, yet the Japanese government is eagerly pushing to restart reactors, against the will of its people, and without learning true lessons from Fukushima.

The Fukushima and Chernobyl nuclear disasters showed us once again that nuclear reactors are potentially dangerous. None of the world's 436 nuclear reactors are immune to human errors, natural disasters, or any of the many other serious incidents that could cause a disaster. Millions of people who live near nuclear reactors are at risk. The disaster in Fukushima Daiichi nuclear plant is clearly worse than the 1979 partial meltdown at Three Mile Island in Pennsylvania, yet not as grave as the 1986 explosion at the Chernobyl nuclear plant, which spread radioactive material over large portions of Europe.

THE ROLE OF ENGINEERS IN SUSTAINABILE DEVELOPMENT AND ECOLOGY

On the basis of the two presented cases, many ethical questions, dilemmas and considerations could arise. It is not easy to make a compromise between progress and ecology, between reliability and sustainability, between technically practical, viable, safe and economic requirements, between moral responsibility to people and the whole environment and obligations to future generations. Engineers have obligations to future generations that could be harmed by irresponsible engineering activities, because it may take decades and generations for products and facilities to have adverse effects. They should not act using immoral and unethical rules and laws. Engineers should not have a profit in mind in the first place and they should not be bribed and corruptible. They should always keep in mind the moral responsibility and obligations toward society as a whole. Their professional ethical standards have to transcend commonly accepted morality.

Engineering ethics is a crucial matter essential for our survival. It is not an option or a luxury. The human race will not survive the 21st century using the engineering ethics of the 20th century. Why is that so? The nuclear and space age that we live in, encourage the vigorous progress of science. Human technology is developing very fast. But will human ethics have grown as strong? Regardless of its scale and power, any technology is governed by the ethics of its operator. In the case of the Chernobyl nuclear disaster, it seems that two engineers in charge of the control room, decided to experiment, to play with the nuclear reactor. Thereby they caused the biggest nuclear disaster so far. In the 19th century there was no machine, no power plant like today's nuclear power plant, that was dangerous to this extend that could cause such massive destruction as today's misuse of nuclear energy.

The main problem is that we have allowed our technology to get away from our ethics. We can do so much more now than we could in previous centuries. Therefore our ethical responsibility is so much more than it once was. Technology has changed ethics we just haven't fully realized that yet. Technology has changed ethics because technology has changed the scope of human action.

Engineering profession has a significant role to play in sustainability. Engineers work to enhance the welfare, health and safety of all, with the minimal use of natural resources and paying due regard to the environment and the sustainability of resources. Their work is influenced by the opportunities and challenges that sustainability brings. Engineers are the providers of options and solutions to maximize social value and minimize environmental impact. It can be summarized in six principles to guide and motivate engineers when making decisions for clients, employers and society which affect sustainability [17]: 1. Contribute to building a sustainable society, present and future; 2. Apply professional and responsible judgment and take a leadership role; 3. Do more than just comply with legislation and codes; 4. Use resources efficiently and effectively; 5. Seek multiple views to solve sustainability challenges; 6. Manage risk to minimize adverse impact to people or the environment.

The goal of sustainable development is to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising quality of life for future generations. Sustainable development stands on two concepts: needs, for example the essential needs of the world's poor; and limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

According to Engineering Council [17], the following principles have been agreed in the UK to achieve sustainable development: 1. living within environmental goals; 2. ensuring a strong, healthy and just society; 3. promoting good governance; 4. achieving a sustainable economy; 5. using sound science responsibly. To accomplish all this goals and to be a engineer of a high quality, modern engineers have to study, not only engineering, but also ethics and philosophy in order to understand relationships between man, nature and the universe and thus to become a humanist who respects, protects and welcomes all life on Earth. They have to recognize the importance of sociological and cultural context of the engineering profession.

Modern engineers also have to develop spiritual intelligence. Spiritual intelligence can be described symbolically as the backbone of human consciousness, responsible for character building and meaning making. Developing spiritual intelligence is more of an experiential rather than a theoretical process. The language of spiritual intelligence is the language of the heart. Growing in spiritual intelligence, engineers grow in their action logic from the perception of "What I can get ..." to "What I can contribute ... ". The practice of self-reflection and contemplation enhances development of spiritual intelligence, and a depth of compassion and benevolence to all life on Earth develops as well. Thus, modern engineer will develop the ability to act with wisdom and compassion, while maintaining inner and outer peace (equanimity), regardless of the circumstances. All these qualities are necessary for contemporary engineer, in order to become a humanist who, while working in his profession, respects, protects and welcomes all life on Earth.

Danah Zohar [18] defined 12 principles underlying spiritual intelligence: 1. Self-awareness: Knowing what I believe in and value, and what deeply motivates me; 2. Spontaneity: Living in and being responsive to the moment; 3. Being vision- and value-led: Acting from principles and deep beliefs, and living accordingly; 4. Holism: Seeing larger patterns, relationships, and connections; having a sense of belonging; 5. Compassion: Having the quality of "feeling-with" and deep empathy; 6. Celebration of diversity: Valuing other people for their differences, not despite them; 7. Field independence: Standing against the crowd and having one's own convictions; 8. Humility: Having the sense of being a player in a larger drama, of one's true place in the world; 9. Tendency to ask fundamental "Why?" questions: Needing to understand things and get to the bottom of *them; 10. Ability to reframe: Standing back from a situation or problem and seeing the bigger picture or wider context; 11. Positive use of adversity: Learning and growing from mistakes, setbacks, and suffering; 12. Sense of vocation: Feeling called upon to serve, to give something back.*

Robert Emmons [19] defines spiritual intelligence as the adaptive use of spiritual information to facilitate everyday problem solving and goal attainment. He originally proposed 5 components of spiritual intelligence: 1. The capacity to transcend the physical and material; 2. The ability to experience heightened states of consciousness; 3. The ability to sanctify everyday experience; 4. The ability to utilize spiritual resources to solve problems; 5. The capacity to be virtuous.

Ancient Chinese people summarized all these highest virtues in three Chinese words: Zhen (truth, truthfulness), Shan (kindness, benevolence, compassion) and Ren (endurance, forbearance, tolerance) [20]. In ancient China when moral values still prevailed, there was only one law for judging a person – virtue (de - in Chinese language). Ancient Chinese people stressed cultivation of one's xinxing (a Chinese idiom for the mind or heart nature, moral character and ethics). A Chinese proverb says, "A man without any virtue is no more than a beast". When a person does not have any virtue left, he is no longer considered worthy of being a human and therefore should have no place in the human society. From this, one can see how highly virtue was regarded in ancient China. Therefore, virtue, ethics and moral should be deeply rooted in the history, society and culture of human beings [20].

CONCLUSION

Engineering ethics is a crucial point and essential for our survival. It is not an option or a luxury. Engineers have to be aware of ethics as they make choices during their professional practice. Therefore, a clear understanding and application of engineering ethics to ecology and sustainable development is needed like never before. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct including honesty, impartiality, fairness, and equity, and do so in the absence of bribe and corruption. They should also contribute to environmental protection and to sustaining the balance in nature. To be an engineer of a high quality one has to study, not only engineering, but also ethics and philosophy, thus to develop spiritual intelligence in order to understand relationships between man, nature and the universe and thus to become a humanist who respects, protects and welcomes all life on our blue planet, the Earth.

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